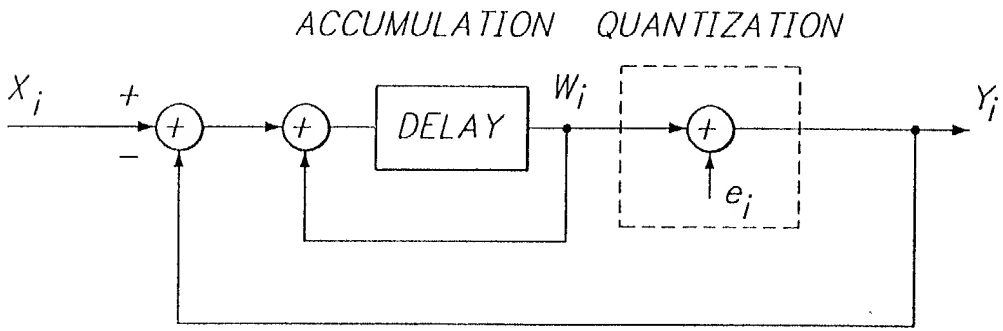


FIG. 1

Accumulator $G_n=G_{n-1}+0.6875-INT(G_{n-1})$	Data Stream $R_n=INT(G_n)$
0.6875	0
1.375	1
1.0625	1
0.75	0
1.4375	1
1.125	1
0.8125	0
1.5	1
1.1875	1
0.875	0
1.5625	1
1.25	1
0.9375	0
1.625	1
1.3125	1
1	1
0.6875	0

FIG. 2

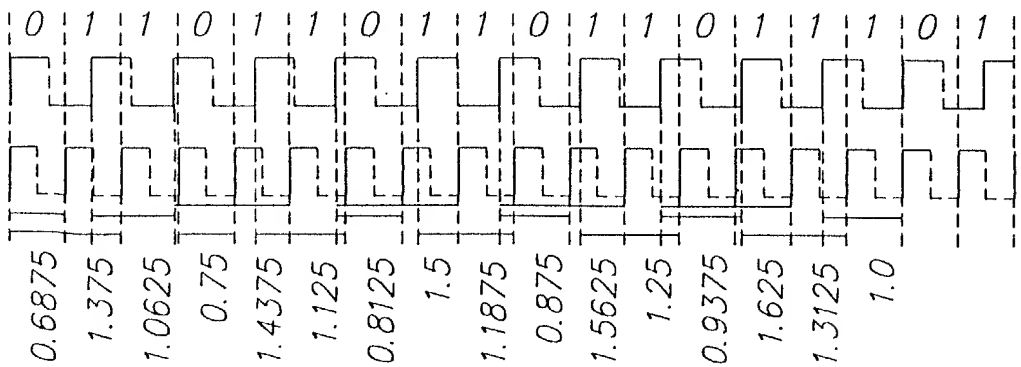


FIG. 3

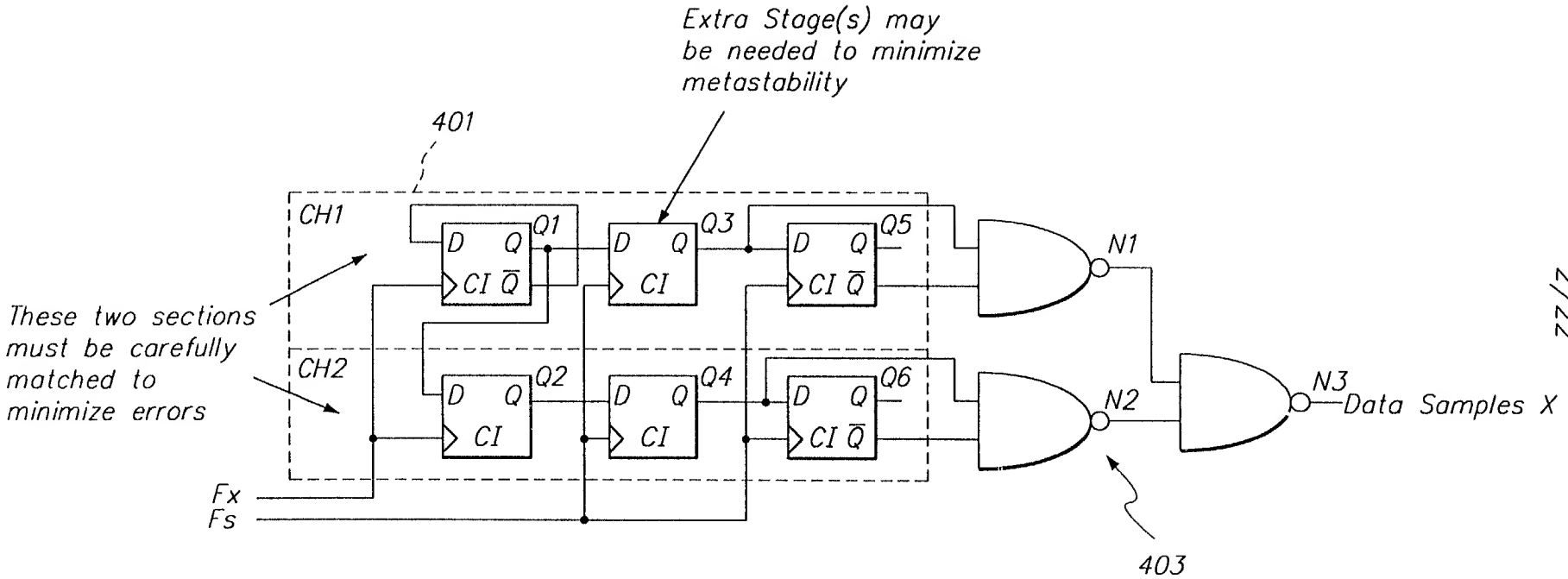

Extra Stage(s) may
be needed to minimize
metastability
401
CH1
CH2
These two sections
must be carefully
matched to
minimize errors
D Q
CI Q̄
Q1
Q2
Q3
Q4
Q5
Q6
N1
N2
N3
Data Samples X
Fx
Fs
403

Fig. 4

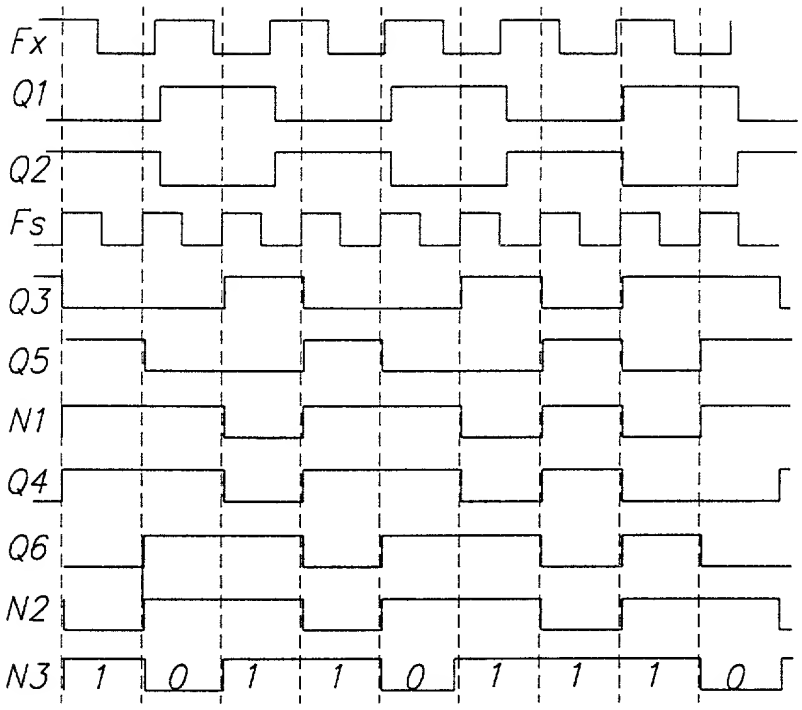

Fx
Q1
Q2
Fs
Q3
Q5
N1
Q4
Q6
N2
N3
1 0 1 1 0 1 1 1 0

FIG. 5

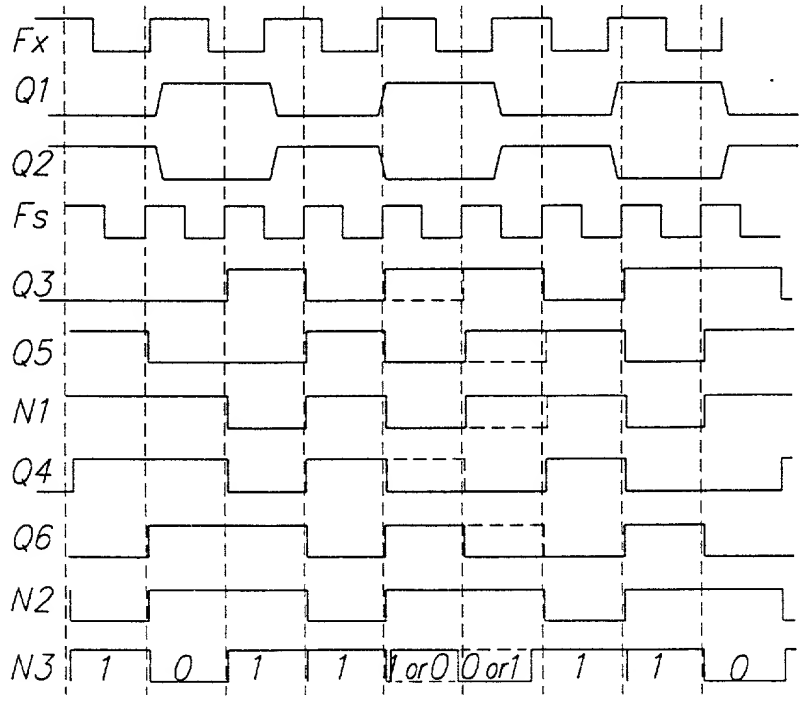

Fx
Q1
Q2
Fs
Q3
Q5
N1
Q4
Q6
N2
N3
1 0 1 1 1 or 0 0 or 1 1 1 0

FIG. 6

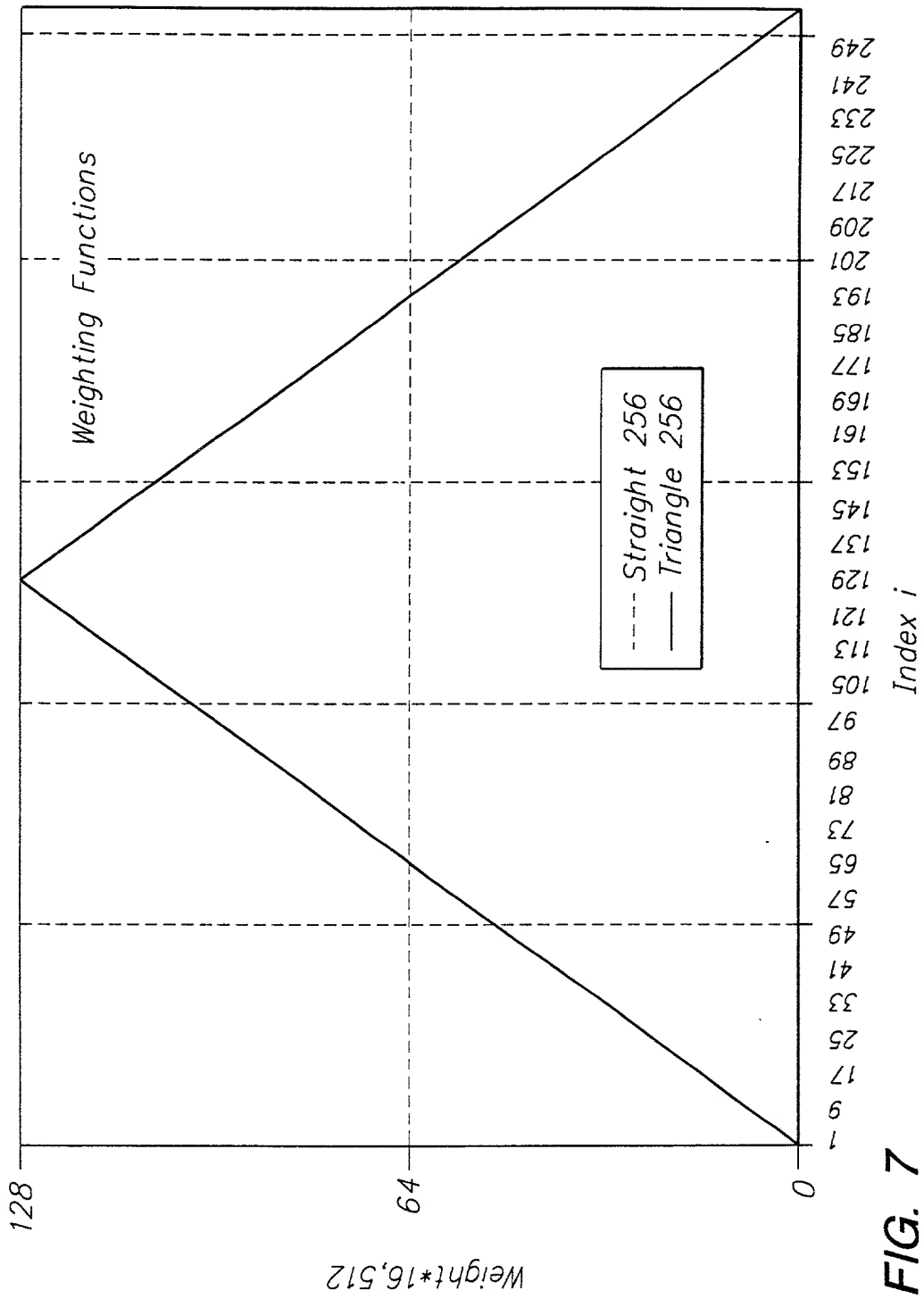

Weighting Functions
Straight 256
Triangle 256
Weight*16,512
128
64
0
1
9
17
25
33
41
49
57
65
73
81
89
97
105
113
121
129
137
145
153
161
169
177
185
193
201
209
217
225
233
241
249
Index i

FIG. 7

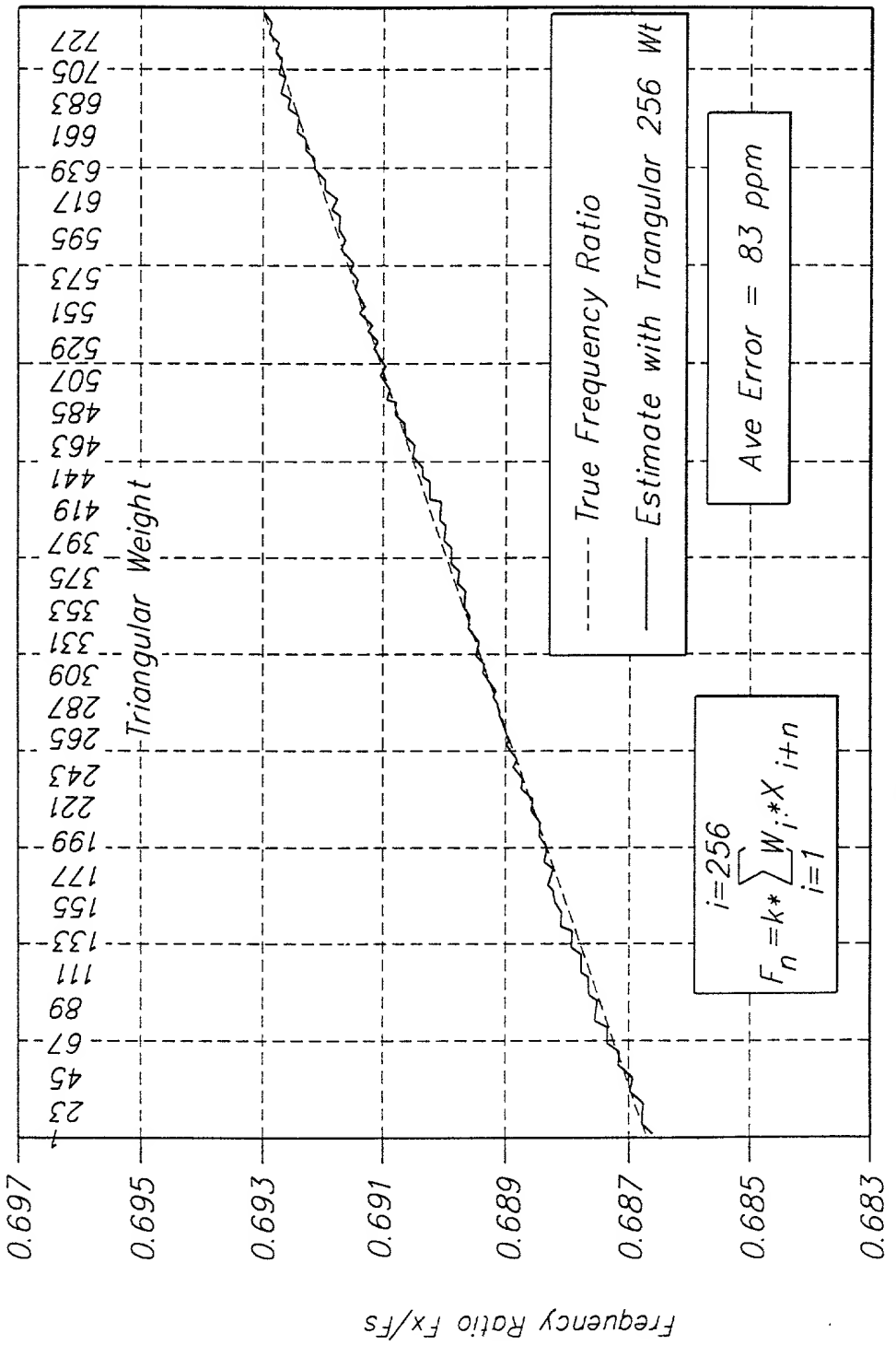

Frequency Ratio Fx/Fs
0.697
0.695
0.693
0.691
0.689
0.687
0.685
0.683
Triangular Weight
1
23
45
67
89
111
133
155
177
199
221
243
265
287
309
331
353
375
397
419
441
463
485
507
529
551
573
595
617
639
661
683
705
727
Samples
True Frequency Ratio
Estimate with Trangular 256 Wt
Ave Error = 83 ppm
$F_n = k^* \sum_{i=1}^{i=256} W_i * X_{i+n}$

FIG. 9

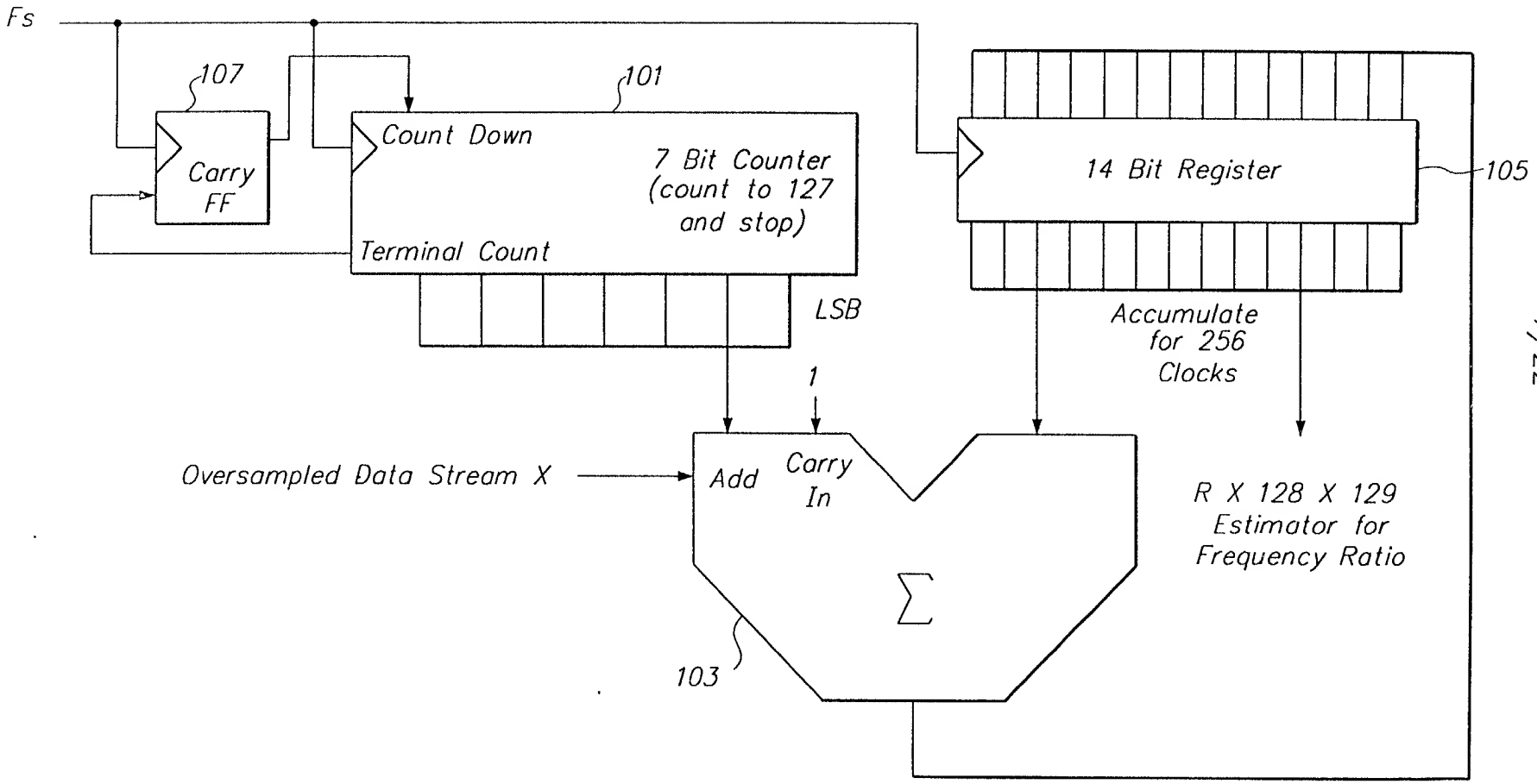

Fs
107
101
Carry FF
Count Down
7 Bit Counter (count to 127 and stop)
Terminal Count
LSB
14 Bit Register
105
Accumulate for 256 Clocks
1
Oversampled Data Stream X
Add
Carry In
Σ
103
R X 128 X 129 Estimator for Frequency Ratio

FIG. 10

Observed Frequency Data Stream X	Weight W	Fr Ratio = Reference Frequency/ Sample Frequency =
1	1	0.6875
1	2	
0	3	
1	4	
1	5	
0	6	
1	7	
1	8	
0	9	
1	10	
1	11	
1	12	
0	13	
1	14	
1	15	
0	16	
1	17	
1	18	
0	19	
1	20	
1	21	
0	22	
1	23	
1	24	
0	25	
1	26	
1	27	
1	28	
0	29	
1	30	
1	31	
0	32	
1	33	
1	34	
0	35	
1	36	
1	37	
0	38	
1	39	
1	40	
0	41	
1	42	
1	43	

FIG. 11A-1

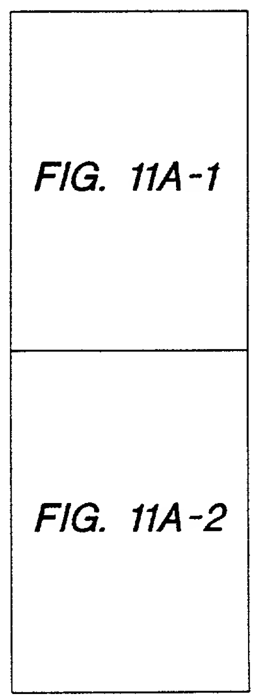


FIG. 11A

			Frequency Estimate		Integration
		Correct Phase	$F_n = \sum_i (W_i * X_{i+n})$ F	ΔF_i = F_i −Fr Ratio ΔF	PF_n = $PF_{n-1} * k * \Delta F_i$ Pf
0	44				
1	45				
1	46				
1	47				
0	48				
1	49				
1	50				
0	51				
1	52				
1	53				
0	54				
1	55				
1	56				
0	57				
1	58				
1	59				
0	60				
1	61				
1	62				
1	63				
0	64				
1	64	−53.714763	0.686058	−0.001442	−55.876923
1	63	−54.394811	0.686058	−0.001442	−56.615385
0	62	−55.066978	0.686058	−0.001442	−57.353846
1	61	−55.731139	0.686058	−0.001442	−58.092308
1	60	−56.387171	0.686058	−0.001442	−58.830769
0	59	−57.034949	0.686058	−0.001442	−59.569231
1	58	−57.674350	0.686058	−0.001442	−60.307692

FIG. 11A-2

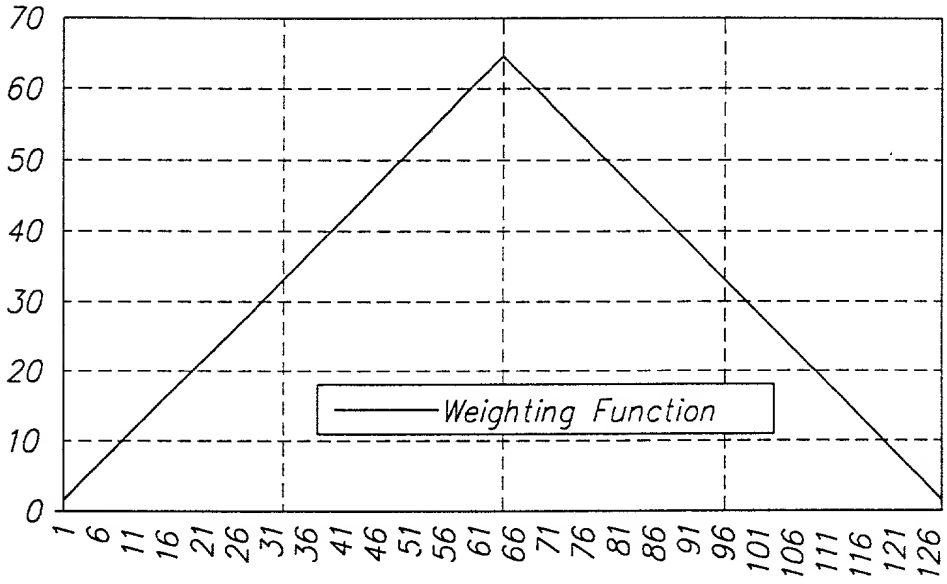
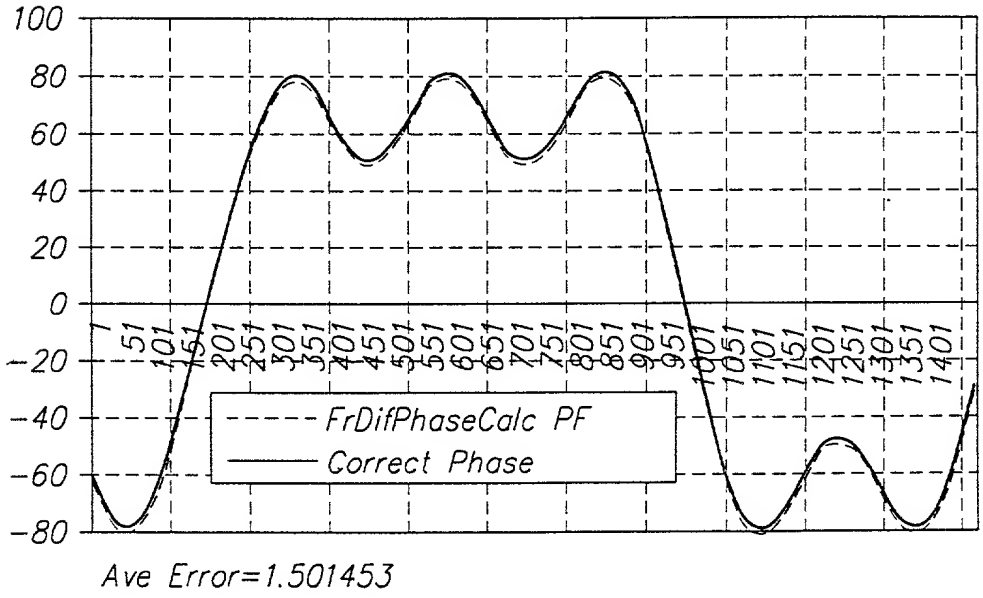


FIG. 11B



Ave Error=1.501453

FIG. 11C

Observed Frequency Data Stream X	Weight W	$Y_i = X_i - FrRatio$ Y	$PX_i = PX_{i-1} + Y_i$ Px	Fr Ratio = Reference Frequency/ Sample Frequency = 0.6875
1	1	0.3125	0.0000	
1	2	0.3125	0.3125	
0	3	−0.6875	−0.3750	
1	4	0.3125	−0.0625	
1	5	0.3125	0.2500	
0	6	−0.6875	−0.4375	
1	7	0.3125	−0.1250	
1	8	0.3125	0.1875	
0	9	−0.6875	−0.5000	
1	10	0.3125	−0.1875	
1	11	0.3125	0.1250	
1	12	0.3125	0.4375	
0	13	−0.6875	−0.2500	
1	14	0.3125	0.0625	
1	15	0.3125	0.3750	
0	16	−0.6875	−0.3125	
1	17	0.3125	0.0000	
1	18	0.3125	0.3125	
0	19	−0.6875	−0.3750	
1	20	0.3125	−0.0625	
1	21	0.3125	0.2500	
0	22	−0.6875	−0.4375	
1	23	0.3125	−0.1250	
1	24	0.3125	0.1875	
0	25	−0.6875	−0.5000	
1	26	0.3125	−0.1875	
1	27	0.3125	0.1250	
1	28	0.3125	0.4375	
0	29	−0.6875	−0.2500	
1	30	0.3125	0.0625	
1	31	0.3125	0.3750	
0	32	−0.6875	−0.3125	
1	33	0.3125	0.0000	
1	34	0.3125	0.3125	
0	35	−0.6875	−0.3750	
1	36	0.3125	−0.0625	
1	37	0.3125	0.2500	
0	38	−0.6875	−0.4375	
1	39	0.3125	−0.1250	
1	40	0.3125	0.1875	
0	41	−0.6875	−0.5000	
1	42	0.3125	−0.1875	
1	43	0.3125	0.1250	

FIG. 12A-1

FIG. 12A-1

FIG. 12A-2

FIG. 12A

0	44	−0.6875	−0.5625		
1	45	0.3125	−0.2500		
1	46	0.3125	0.0625		
1	47	0.3125	0.3750		
0	48	−0.6875	−0.3125		
1	49	0.3125	0.0000		
1	50	0.3125	0.3125		
0	51	−0.6875	−0.3750		
1	52	0.3125	−0.0625		
1	53	0.3125	0.2500		
0	54	−0.6875	−0.4375		
1	55	0.3125	−0.1250		
1	56	0.3125	0.1875		
0	57	−0.6875	−0.5000		
1	58	0.3125	−0.1875		
1	59	0.3125	0.1250		
0	60	−0.6875	−0.5625		
1	61	0.3125	−0.2500		
1	62	0.3125	0.0625		
1	63	0.3125	0.3750	Correct Phase	$PP_n = k*\sum_i (W_i + PX_{i+n})$ PP
0	64	−0.6875	−0.3125		
1	64	0.3125	0.0000	−53.714763	−55.876923
1	63	0.3125	0.3125	−54.394811	−56.615385
0	62	−0.6875	−0.3750	−55.066976	−57.353846
1	61	0.3125	−0.0625	−55.731139	−58.092308
1	60	0.3125	0.2500	−56.387171	−58.830769
0	59	−0.6875	−0.4376	−57.034949	−59.569231
1	58	0.3125	−0.1250	−57.674350	−60.307692

FIG. 12A-2

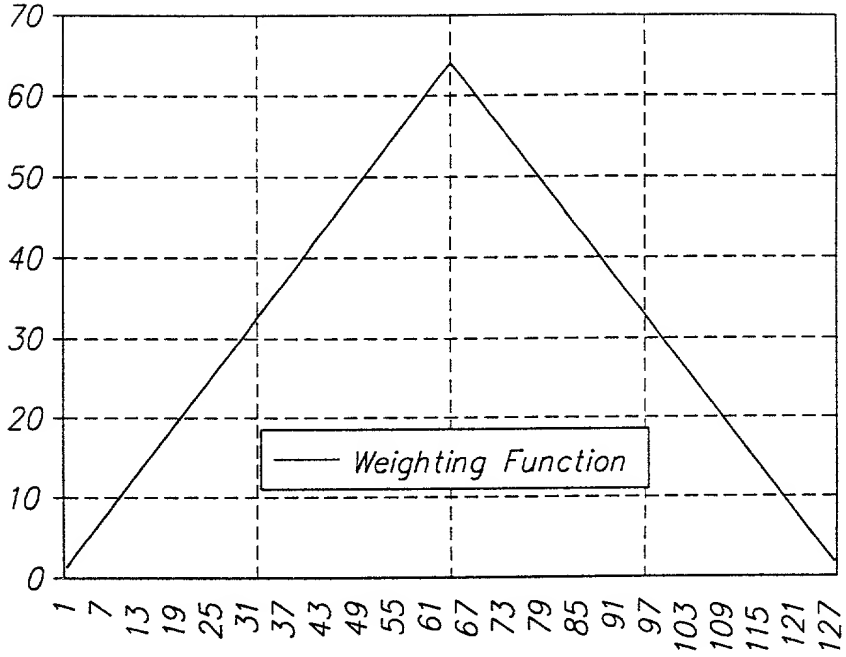
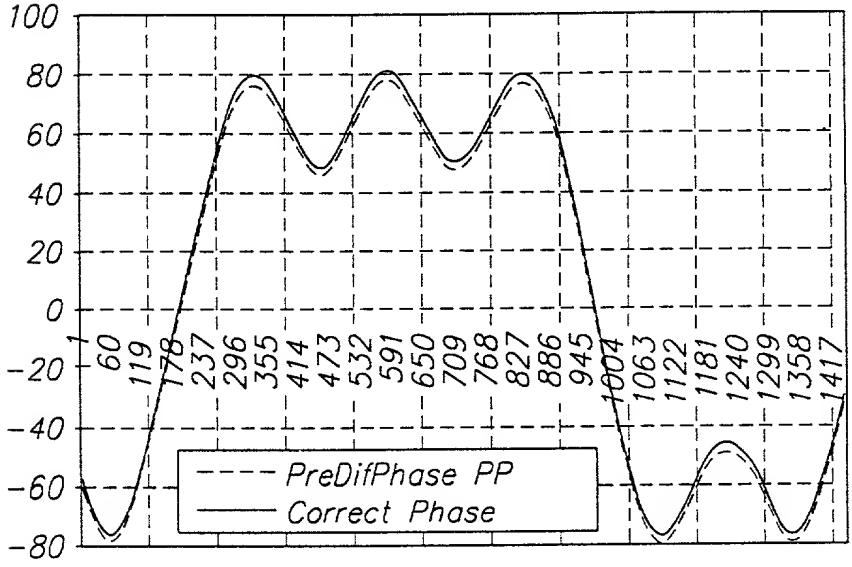


FIG. 12B



Ave Error= 1.501453

FIG. 12C

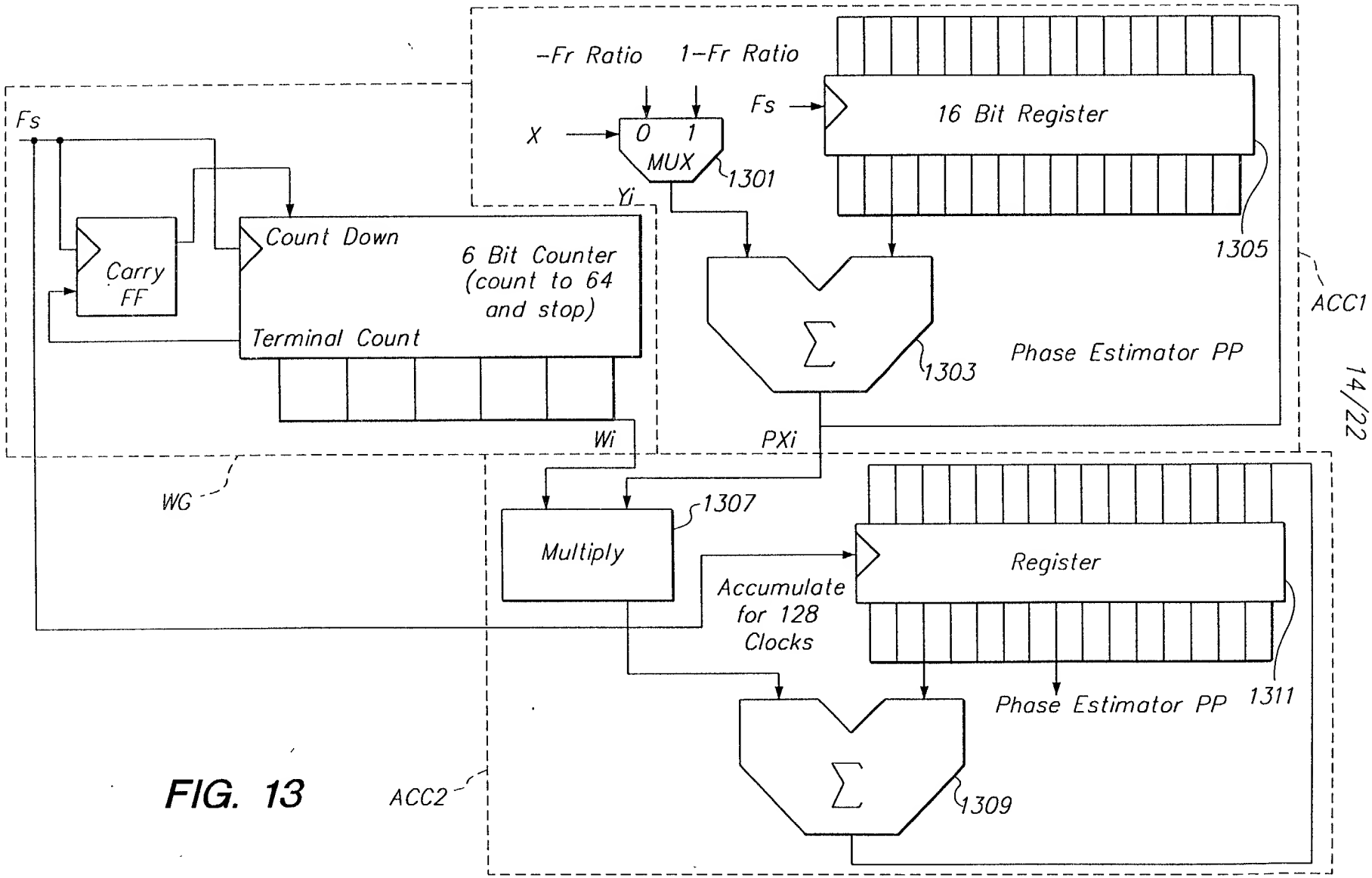

-Fr Ratio
1-Fr Ratio
Fs
X
0
1
MUX
1301
Yi
16 Bit Register
1305
ACC1
Fs
Carry FF
Count Down
6 Bit Counter (count to 64 and stop)
Terminal Count
Wi
Σ
1303
Phase Estimator PP
PXi
14/22
WG
1307
Multiply
Accumulate for 128 Clocks
Register
Phase Estimator PP
1311
Σ
1309
ACC2

FIG. 13

Reference Frequency Data Stream R	Observed Frequency Data System X	$D_i = D_{i-1} + X_i - Ri$ D	Weight W	Fr Ratio= Reference Frequency/ Sample Frequency = 0.6875
1	1	0	1	
1	1	0	2	
0	0	0	3	
1	1	0	4	
1	1	0	5	
0	0	0	6	
1	1	0	7	
1	1	0	8	
1	0	-1	9	
0	1	0	10	
1	1	0	11	
1	1	0	12	
0	0	0	13	
1	1	0	14	
1	1	0	15	
0	0	0	16	
1	1	0	17	
1	1	0	18	
0	0	0	19	
1	1	0	20	
1	1	0	21	
0	0	0	22	
1	1	0	23	
1	1	0	24	
1	0	-1	25	
0	1	0	26	
1	1	0	27	
1	1	0	28	
0	0	0	29	
1	1	0	30	
1	1	0	31	
0	0	0	32	
1	1	0	33	
1	1	0	34	
0	0	0	35	
1	1	0	36	
1	1	0	37	
0	0	0	38	
1	1	0	39	
1	1	0	40	
1	0	-1	41	
0	1	0	42	

FIG. 14A-1

FIG. 14A-1

FIG. 14A-2

FIG. 14A

1	1	0	43		
1	0	−1	44		
0	1	0	45		
1	1	0	46		
1	1	0	47		
0	0	0	48		
1	1	0	49		
1	1	0	50		
0	0	0	51		
1	1	0	52		
1	1	0	53		
0	0	0	54		
1	1	0	55		
1	1	0	56		
1	0	−1	57		
0	1	0	58		
1	1	0	59		
1	0	−1	60		
0	1	0	61		
1	1	0	62		
1	1	0	63		
0	0	0	64		
1	1	0	64	−53.714763	−55.876923
1	1	0	63	−54.394811	−56.615385
0	0	0	62	−55.066978	−57.353846
1	1	0	61	−55.731139	−58.092308
1	1	0	60	−56.387171	−58.830769
0	0	0	59	−57.034949	−59.569231
1	1	0	58	−57.674350	−60.307692

$k_0 = 16$

Correct Phase	$PI_n = k_0 + k_1 * \sum_i (W_i * D_{i+n})$ F

FIG. 14A-2

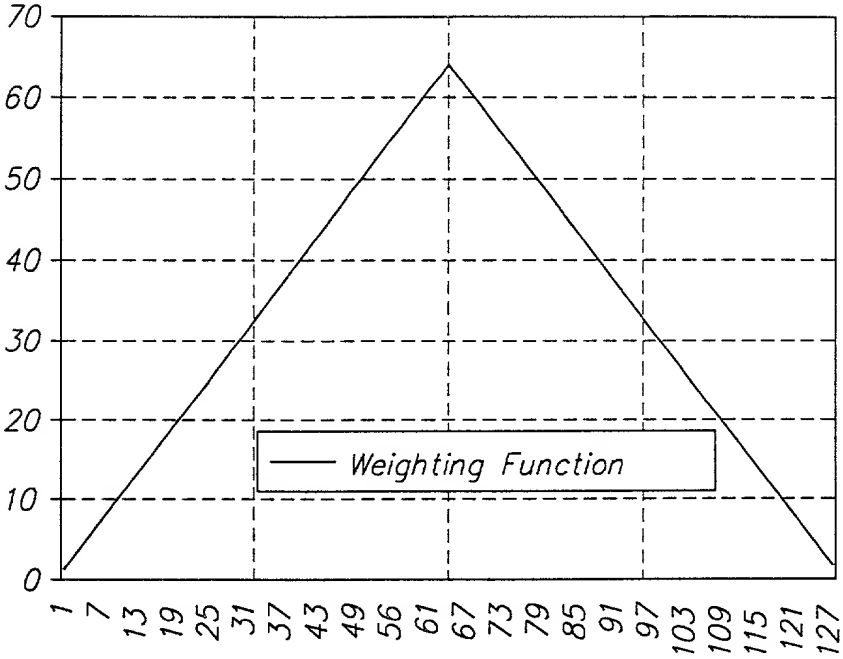
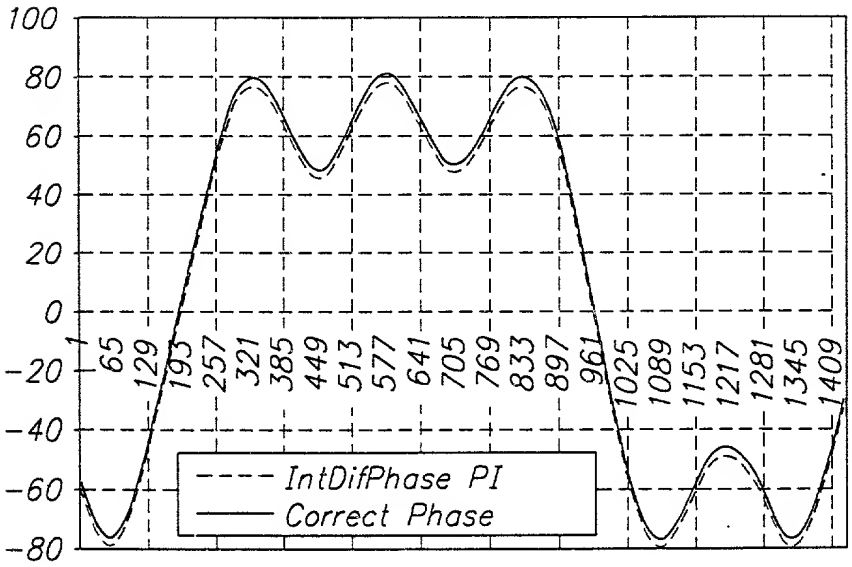


FIG. 14B



Ave Error= 1.501453

FIG. 14C

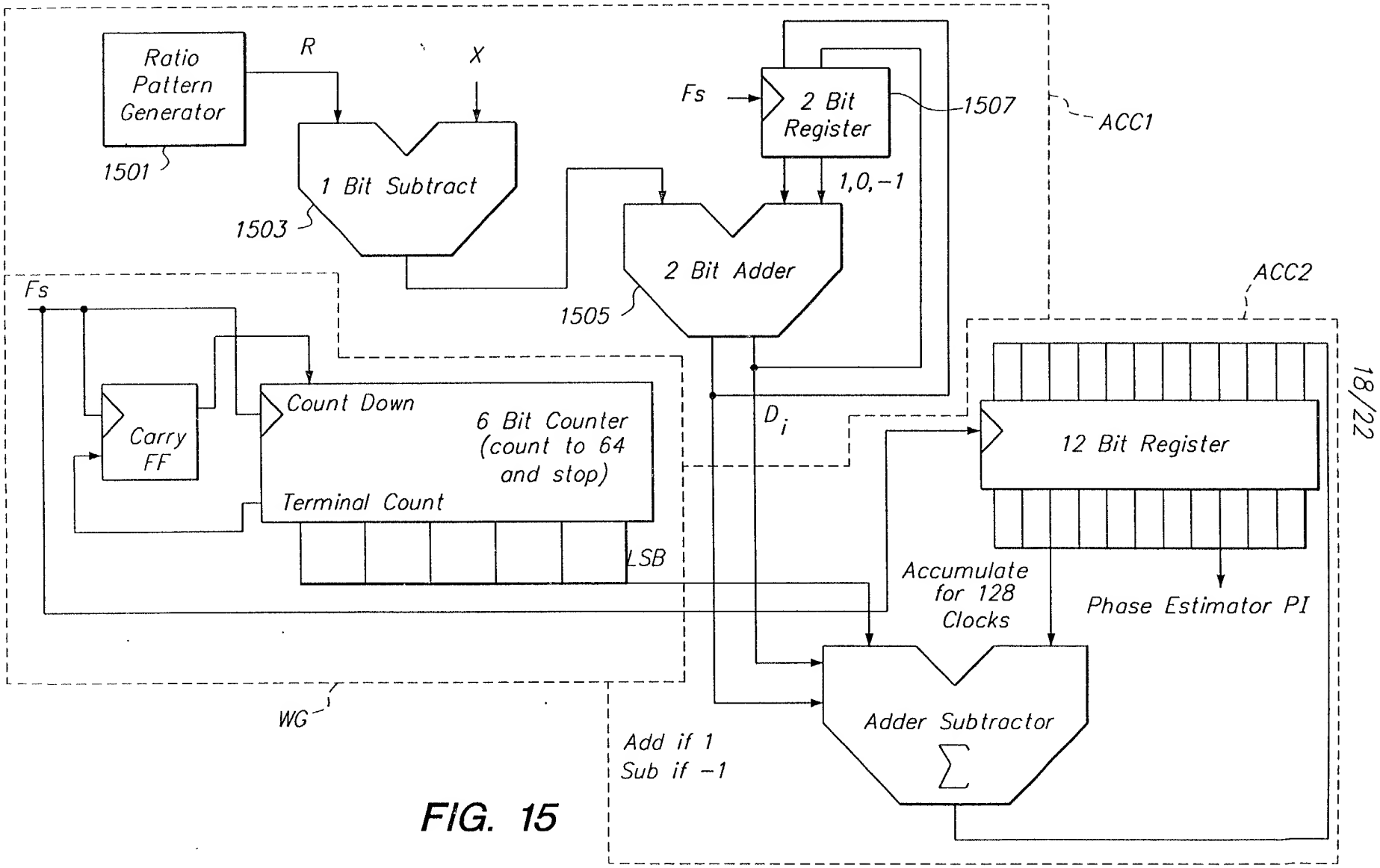

Ratio Pattern Generator
1501
R
X
1 Bit Subtract
1503
Fs
2 Bit Register
1507
ACC1
1,0,-1
2 Bit Adder
1505
ACC2
Fs
Carry FF
Count Down
6 Bit Counter (count to 64 and stop)
Terminal Count
LSB
D_i
12 Bit Register
18/22
Accumulate for 128 Clocks
Phase Estimator PI
WG
Add if 1
Sub if -1
Adder Subtractor
Σ

FIG. 15

Reference Frequency Generator RG	Reference Frequency Data Stream R	Observed Frequency Data System X	$D_i = D_{i-1} + X_i - R_i$ D	Weight W	Fr Ratio= Reference Frequency/ Sample Frequency = 0.6875
1.5	1	1	0	−0.5	
1.1875	1	1	0	−2	
0.875	0	0	0	−4.5	
1.5625	1	1	0	−8	
1.25	1	1	0	−12.5	
0.9375	0	0	0	−18	
1.625	1	1	0	−24.5	
1.3125	1	1	0	−32	
1	1	0	−1	−40.5	
0.6675	0	1	0	−50	
1.375	1	1	0	−60.5	
1.0625	1	1	0	−72	
0.75	0	0	0	−84.5	
1.4375	1	1	0	−98	
1.125	1	1	0	−112.5	
0.8125	0	0	0	−128	
1.5	1	1	0	−144.5	
1.1875	1	1	0	−162	
0.875	0	0	0	−180.5	
1.5625	1	1	0	−200	
1.25	1	1	0	−220.5	
0.9375	0	0	0	−242	
1.625	1	1	0	−264.5	
1.3125	1	1	0	−288	
1	1	0	−1	−312.5	
0.6875	0	1	0	−338	
1.375	1	1	0	−364.5	
1.0625	1	1	0	−392	
0.75	0	0	0	−420.5	
1.4375	1	1	0	−450	
1.125	1	1	0	−480.5	
0.8125	0	0	0	−512	
1.5	1	1	0	−644.5	
1.1875	1	1	0	−578	
0.875	0	0	0	−612.5	
1.5625	1	1	0	−648	
1.25	1	1	0	−684.5	
0.9375	0	0	0	−722	
1.625	1	1	0	−760.6	
1.3125	1	1	0	−800	
1	1	0	−1	−840.5	
0.6875	0	1	0	882	

FIG. 16A-1

FIG. 16A-2

FIG. 16A

FIG. 16A-1

1.375	1	1	0	−924.5		
1.0625	1	0	−1	−968		
0.75	0	1	0	−1012.5		
1.4375	1	1	0	−1068		
1.125	1	1	0	−1104.5		
0.8125	0	0	0	−1152		
1.5	1	1	0	−1200.5		
1.1875	1	1	0	−1250		
0.875	0	0	0	−1300.5		
1.5625	1	1	0	−1352		
1.25	1	1	0	−1404.5		
0.9375	0	0	0	−1458		
1.625	1	1	0	−1512.5		
1.3125	1	1	0	−1568		
1	1	0	−1	−1624.5		
0.6875	0	1	0	−1682		
1.375	1	1	0	−1740.5		
1.0625	1	0	−1	−1800		
0.75	0	1	0	−1860.5	Correct Phase	$PC_n = k*(D_n - frac(RG_n) + 0.5 + \sum_i (W_i * X_{i+n-64}))$
1.4375	1	1	0	−1922		PC
1.125	1	1	0	−1984.5		
0.8125	0	0	0	−2048		
1.5	1	1	0	2048	−53.374738	−55.507692
1.1875	1	1	0	1984.5	−54.054787	−56.246154
0.875	0	0	0	1922	−54.730895	−56.984615
1.5625	1	1	0	1860.5	−55.399059	−57.723077
1.25	1	1	0	1800	−56.059155	−58.461538
0.9375	0	0	0	1740.5	−56.711060	−59.200000
1.625	1	1	0	1682	−57.354650	−59.938462
1.3125	1	1	0	1624.5	−57.939800	−60.676923

FIG. 16A-2

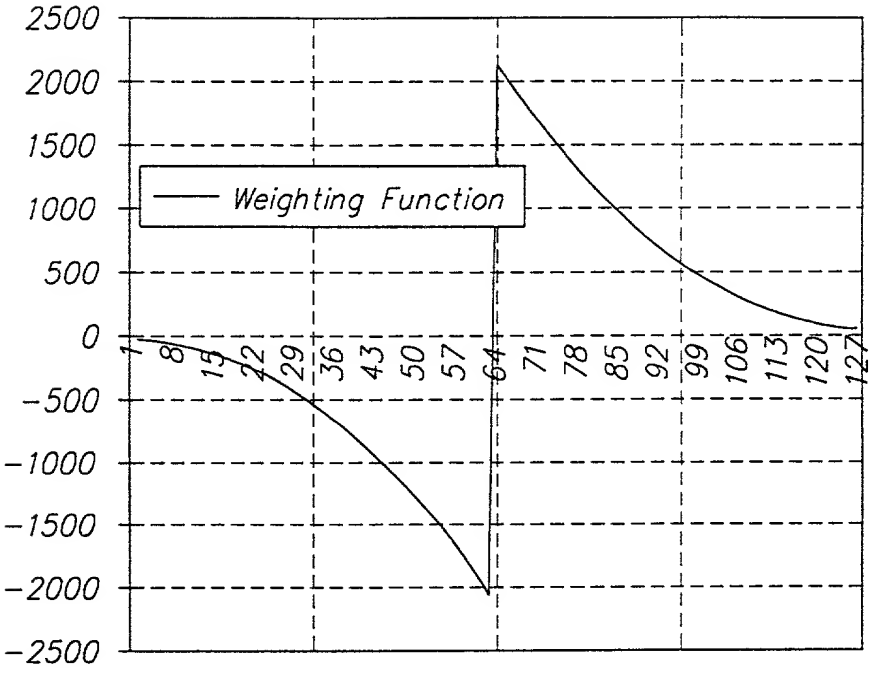
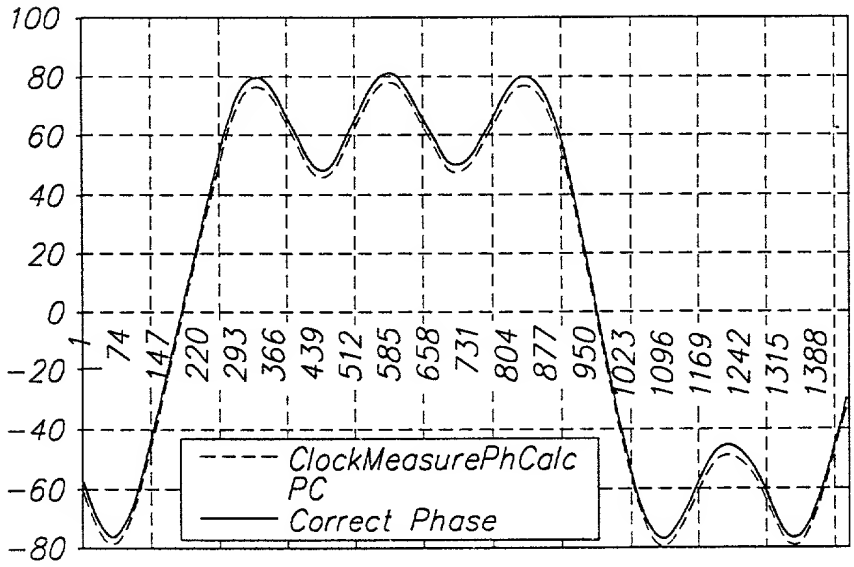


FIG. 16B



Ave Error= 1.501476

FIG. 16C

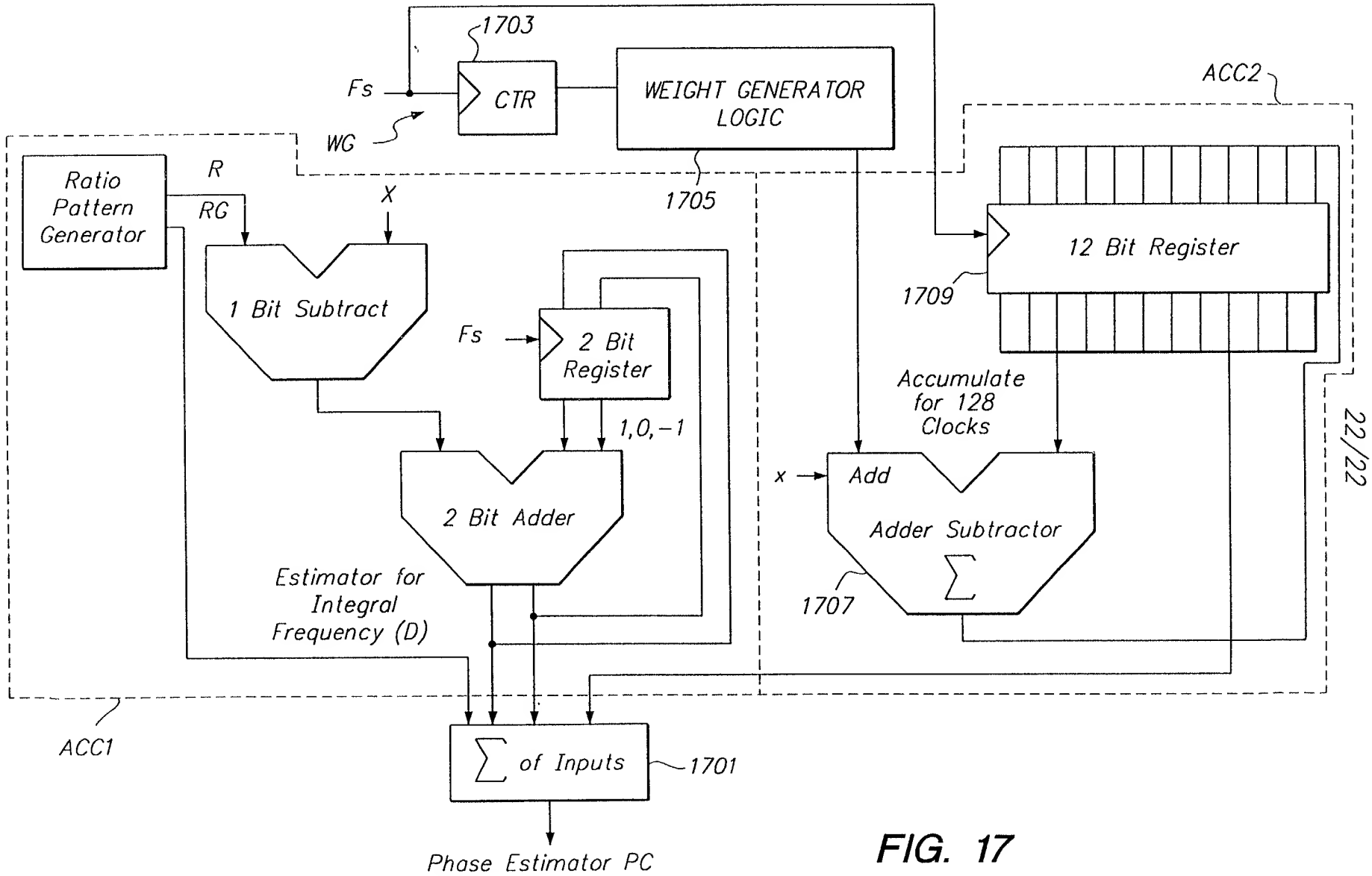

1703
Fs
CTR
WEIGHT GENERATOR LOGIC
ACC2
WG
Ratio Pattern Generator
R
RG
X
1705
12 Bit Register
1709
1 Bit Subtract
Fs
2 Bit Register
Accumulate for 128 Clocks
1,0,-1
2 Bit Adder
x
Add
Adder Subtractor
Σ
1707
Estimator for Integral Frequency (D)
22/22
ACC1
Σ of Inputs
1701
Phase Estimator PC

FIG. 17